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Sensitivity and Uncertainty Analysis of Expected Loss Costs in Hurricane Models

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

SENSITIVITY AND UNCERTAINTY ANALYSIS OF EXPECTED
LOSS COSTS IN HURRICANE MODELS

A thesis submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

in

STATISTICS

by

Antonio Ricardo Hudson

2012

To: Dean Kenneth G. Furton
College of Arts and Science

This thesis, written by Antonio Ricardo Hudson, and entitled Sensitivity and Uncertainty Analysis of Expected Loss Costs in Hurricane Models, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

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Date of Defense: June 18, 2012

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Florida International University, 2012

ABSTRACT OF THE THESIS
SENSITIVITY AND UNCERTAINTY OF EXPECTED LOSS COSTS IN
HURRICANE MODELS

by

Antonio Ricardo Hudson

Florida International University, 2012

Miami, Florida

Professor Sneh Gulati, Co-Major Professor

Professor B. M. Golam Kibria, Co-Major Professor

The Public Hurricane Model developed at FIU by a team of scientists has to be certified by the Florida Commission on Hurricane Loss Projection Methodology. The commission ensures that all hurricane loss models meet certain standards, as models are used extensively by regulators and insurance firms to produce inputs used in the homeowner insurance rate making process. The focus of this thesis is to conduct sensitivity and uncertainty analysis through the calculation of standardized regression coefficients and expected percentage reductions in expected loss costs in order to meet the commission standards.

The commission approved the model after very extensive and rigorous review by a panel of experts. The results generated for sensitivity and uncertainty, form S-6, showed the importance of the Holland B parameter regardless of hurricane category, with the radius of maximum winds increasing in importance for stronger hurricanes.

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Chapter 1

Introduction

1.1 Background

The Florida Commission on Hurricane Loss Projection Methodology (FCHLPM) has, as its primary purpose, the regulation of hurricane loss models to ensure that they meet established criteria. The examination of models is required so that “reliable projections of hurricane losses are necessary to assure that rates for residential insurance are neither excessive nor inadequate” (FCHLPM 2007). The commission encourages all models submitted for approval to use computer modeling, and it requires that a series of stringent guidelines be met in order to make sure “that consumers are charged lawful rates for residential property insurance coverage” (FCHLPM 2007).

The Florida Public Hurricane Loss Model (FPHLM) is a joint effort among members of different fields, such as meteorology, engineering, actuarial studies, and statistics, from universities all over the state of Florida. Prior to its conception, the only models available were proprietary models. The programming and design of these models is not publicly available for review, and therefore proper evaluation of the methodology within proprietary models can be difficult. The development of the FPHLM makes it possible to test and compare the results of these proprietary models in order to make sure that insurance costs for the general public are adequately established. Once it had been reviewed and accepted by the commission funding was granted to maintain and update it by the Office of Insurance Regulation (OIR).

The model consists of three separate components: a wind model, a vulnerability model, and an insured loss model. The wind model is dedicated to simulating hurricanes,

their wind speeds and their decay, once on land, on the basis of historical data. The vulnerability model consists of the engineering simulation of the damage that particular wind speeds inflict upon a structure, its interior, and contents. Finally, the insured loss model is responsible for generating loss costs depending on insurance policy features, and on particular wind speeds and how they affect different construction types. For further details on the FPHLM please refer to Hamid, et al. (2008, 2010).

1.2 Problem Description

It is of interest to the analysis of the insured loss model and to the FCHLPM to know the effects that particular predictor variables have on the expected loss cost function. Therefore, it is necessary to conduct sensitivity analysis (SA) and uncertainty analysis (UA) of the loss costs. Sensitivity analysis can be defined as the “study of changes in a model output produced by varying model inputs. This definition includes not only the usual one-at-a-time method, but several classes of techniques” (Los Alamos Scientific Laboratory 1979). Uncertainty analysis is generally defined as the “determination of the variation or imprecision in model output resulting from the collective variation in the model inputs” (Iman et al. 2002a).

The analysis was based on the requirements stipulated by the Florida Commission on Hurricane Loss Projection Methodology. They require the analysis of losses caused by hurricanes of different magnitudes (Category 1, Category 3, and Category 5) to hypothetical \$100,000 insured structures with zero deductible policies placed approximately three miles apart throughout South Florida. The maximum wind velocity generated in one hour at a point in the South Florida map was calculated using the

following variables: central pressure, radius of maximum winds, translational velocity, Holland B quantiles, far field pressure, and additional quantiles (these variables are discussed in detail in section 2.1). Maximum wind velocities were then used to calculate the loss cost (LC). Sensitivity analysis and UA were done on the data generated in this fashion (Iman et al. 2002a).

1.3 Project Organization

In order to create a set of programming functions capable of doing SA and UA for the 2010 data correctly, it was necessary to create programming functions that could easily be validated and compared to known results. Therefore, the original programming functions created used the 2005 data generated by the FPHLM, for which SA and UA had already been done. Since SA and UA was conducted in 2005 for a previous version of the model and again in 2010 for a new version of the model, the 2005 results were used to thoroughly validate the programming functions before the 2010 model results became available. Furthermore, it also significantly decreased the waiting time between the reception of the 2010 data and the SA and UA results, which could then be used to validate the model and make any appropriate changes. Because of the different format of the 2005 and the 2010 data not all of the functions created for 2005 were used for the 2010 analysis; in some cases it was necessary to modify the 2005 functions in order to address the format changes.

All analysis was done with the R programming language (R Project 2012). Six different functions were created to address the requirements of the FCHLPM: a function capable of loading all necessary files, a function for Sensitivity, a function for

Uncertainty, a Contour Plotting function, and a Cumulative Relative Frequency function. Each of these functions was created and validated either using the 2005 data in order to mirror the available results from form S-5, Sensitivity and Uncertainty or through traditional programming validation methodology. Form S-5, which lists the requirements for sensitivity and uncertainty according to the FCHLPM in 2005, required sensitivity analysis to be done for LC through the calculation of standardized regression coefficients by hurricane category and each input variable. Uncertainty analysis was carried out through the calculation of expected percentage reductions for LC by hurricane category for each input variable. Contour plots were done for both LC as well as maximum winds for each category hurricane. The Cumulative Relative Frequency distribution compares the hurricane categories by LC (see Chapter 2 for details on form S-5).

Once the 2010 data were received it became apparent that changes to some of the functions were necessary because of changes in the format of the data in 2005 and 2010. Validation of these changes occurred through traditional programming validation methodology as well as through testing the new functions on reformatted 2005 data files made to mimic 2010 data files. After these changes, the files required for form S-6, which specifies the sensitivity by the FCHLPM, were generated. The requirements for form S-6 were very similar to those of form S-5, the differences are discussed in detail in Chapter 2. The results were presented to the evaluating team and form S-6, which was responsible for the SA and UA, was approved after very extensive and rigorous review by a panel of experts.

To summarize, the final project organization was as follows:

1. Receive 2005 data and 2010 requirements (FPHLM form S-6).

2. Create functions capable of doing all necessary analysis for 2010 requirements using 2005 data.
3. Validation:
 - a. Validate functions by comparing results to 2005 published results (FPHLM form S-5) where 2005 requirements and 2010 requirements are equivalent.
 - b. Validate functions through traditional methods where 2010 requirements differ from 2005 requirements so that no 2005 results are available.
4. Receive 2010 data.
5. Modify functions where necessary to deal with data format differences between 2005 and 2010.
6. Validation:
 - a. Validate functions through traditional methods.
 - b. Validate functions by testing them on reformatted 2005 data made to mimic 2010 data and comparing to 2005 results.
7. Report SA and UA results.

1.4 Disposition

This thesis consists of 6 chapters and 2 appendices. Chapter 1 introduces the problem. Chapter 2 goes through the statistical methodology required to properly analyze the results. Chapter 3 describes in detail the structure, similarities, and differences of the 2005 and the 2010 data. Chapter 4 describes the functions created for forms S-5 and S-6 using the R statistical programming language. Chapter 5 explains the validation process

of the functions. Chapter 6 concludes with the final results as well as future recommendations. The appendices contain the fully commented code as well as the complete set of final results presented to the commission.

Chapter 2

Statistical Methodology

2.1 Procedure for Calculating Loss Costs form S-5, 2005

The standards specified by the FCHLPM required the FIU team to use a linear model in order to calculate maximum wind velocity per hour (V_{\max}). A linear model is of the form:

$$Y = X\beta + \varepsilon$$

where the expected value of the response variable, Y , is a linear combination of the vector of parameters, β . For the hurricane model, the response variable is V_{\max} , and the X matrix is populated for a certain category hurricane at a particular vertex point and a certain hour (1 through 12) by the following variables:

CP = central pressure (in millibars)

R_{\max} = radius of maximum winds (in statute miles: 1 statute mile \approx 1.609 km)

VT = translational velocity (forward speed in miles/hour)

Holland B Quantiles = model shape parameter

FFP = far field pressure (in millibars)

Quantiles for possible additional input variables (optional use)

Central pressure refers to the pressure at the center of the hurricane; low central pressure is associated with stronger category hurricanes. R_{\max} refers to the radius of maximum winds in statute miles; a hurricane with a larger radius has the potential to damage more properties. The translational velocity data gives the forward speed in miles/hour of the hurricane; higher velocities imply a given property spends a shorter amount of time experiencing hurricane force winds. The Holland B parameter is used to better describe the relationship between maximum wind speed and the difference in pressure between

hurricane center and periphery. It should be noted that modeling the surface pressure field using the Holland B parameter “is a significant improvement over modeling the pressure field with empirical models described by only two parameters” (Vickery & Wadhwa 2008). Far field pressure is the ambient atmospheric pressure outside of the hurricane.

The FCHLPM required the calculation of V_{\max} given 100 combinations of each of the input variables in order to perform sensitivity and uncertainty analysis. Once V_{\max} was calculated, it was used to compute the loss cost per hour at each vertex based on the %damage formula given below.

$$\%damage = \frac{V_{\max} - 50}{140 - 50}$$

The percent damage was then used in combination with the loss cost methodology established by the engineering and actuarial models regarding the property type and deductible. This allowed for the calculation of the expected loss costs. However, since the LC calculated is hourly, it was compiled so that “we are looking at maximum total loss costs for each hour for each combination of the (...) variables” (Iman et al. 2002a)

2.2 Sensitivity Analysis for form S-5, 2005

Sensitivity analysis was achieved through the study of two statistics that were considered for the linear model. These are the measures of “the relative influence on the magnitude of V_{Total} (V_{\max}): partial correlation coefficients (PCC) and standardized regression coefficients (SRC)” (Iman et al. 2002a). Standardized regression coefficients measure how changes in the standard deviation of the independent variables affect the standard deviation of the dependent variable, V_{\max} . A large SRC for a particular independent

variable implies that V_{\max} is highly sensitive to changes in the variation of that variable. The calculation of the PCC, which is necessary to calculate the SRC, was done by calculating the correlation of the matrix which includes the 100 values of all input variables as well as the 100 average LC values for each category of hurricane. The correlation matrix R created by the set of correlations can be used to calculate the PCC as follows:

$$PCC_{X_i Y_j} = \frac{-R_{X_i Y_j}^{-1}}{\sqrt{R_{X_i X_i}^{-1} R_{Y_j Y_j}^{-1}}}$$

where X_i refers to each one of the above mentioned predictor variables, and Y_j refers to each one of the 100 LC values created by the possible combinations for each hurricane. The SRC will be calculated by “multiplying the reciprocal of the element in the lower right hand corner of the matrix R^{-1} times the first four elements in the last row” (Iman et al. 2002a) of the R^{-1} matrix.

The SA also required that contour plots be drawn for all models, showing the behavior of different category hurricanes at different locations. In order for plotting to be possible, expected loss costs were averaged over each of the designated vertex points. These points are positioned 3 miles apart in the N-S and E-W directions with (0, 0) representing hurricane landfall, creating a map of South Florida. Plotting the distribution of total LC for each hurricane type further allowed us to properly understand how each of the variables affects LC. Finally, the plotting of the SRC at specific times and grid coordinates, although not required for the 2010 submission of the S-6 form, was used as a validation technique since it was included in the 2005 submission of the S-5 form.

2.3 Uncertainty Analysis for form S-5, 2005

Uncertainty Analysis is centered on the expected percentage reduction (EPR) in the variability of LC created by each one of the predictor variables. Expected percentage reduction values establish much of the variation in the dependent variable, V_{\max} , is caused by each of the independent variables when all other independent variables are held constant. The EPR values show the importance of each of the independent variables in the uncertainty of the dependent variable. The variability reduction is based on the following equation:

$$\text{Expected \% Reduction (EPR) in } \text{Var}(Y) = \frac{\text{Var}(E(Y | X_j))}{\text{Var}(Y)} \times 100$$

where $\text{Var}(E(Y|X_j))$ is the variance of the expected value of Y (in this case LC) given only one of the predictor variables, X_i , is present. In order to do this, all other values of the predictor variables in the matrix are substituted by their means. The substitution of each of the predictor variables by their mean allows them to be ranked in order of their expected % reduction in variability (Iman et al. 2002b). Also, similar to the SA, the plotting of EPR at specific times and grid coordinates, although not required for the 2010 submission, was used as a validation technique.

2.4 Sensitivity and Uncertainty Analysis for form S-6, 2010

The SA and UA for form S-6 follow the same statistical methodology as the 2005 procedure. Changes include that the number of vertices was reduced for form S-6 as well as the fact that different input variables were used and LC were calculated directly. These changes in the requirements made by the FCHLPM meant that SA and UA were done on

LC only. As required by the commission, the final report showed the UA and SA through the calculations of EPR, SRC, cumulative relative frequency (CRF) for Averaged Expected LC. The commission also required contour plots for all of the predictor variables in order to properly establish the relevance of each one in terms of sensitivity and uncertainty when estimating LC for each hurricane category.

Chapter 3

Data

3.1 Input Data for the 2005 Model

The data the model used in 2005 to generate maximum wind velocities and expected loss costs consist of an input file for each category Hurricane (one, three, and five) which contains 100 values for the following input variables: CP, Rmax, VT, Quantile 1 (Holland B), and Quantile 2 (a description of the variables can be found in the statistical methodology section). It should be noted that the Holland B quantiles are not Holland B values, which were not readily available for the 2005 data. Additional input files were generated for each variable, which were used in order to calculate the expected percentage reduction (EPR) values for UA. In each of these files all other variables were replaced with the mean of the 100 values for that variable, allowing for the analysis of the effects of a single variable on LC. In total there were six input files (For inspection, these files can be seen in appendix 2: Data Files).

Table 1: Sample of 2005 input file, all-variable

CP	Rmax	VT	Quantile 1	Quantile 2
979.5	28.76	12.97	0.6762	0.9657
982.4	31.35	16.45	0.0041	0.7213
988.8	22.05	17.59	0.0663	0.6394
979.4	26.44	16.99	0.9609	0.6695

Table 2: Sample of 2005 additional input file for EPR, only CP variable

CP	Rmax	VT	Quantile 1	Quantile 2
979.5	24.66	15.00	0.5006	0.4999
982.4	24.66	15.00	0.5006	0.4999
988.8	24.66	15.00	0.5006	0.4999
979.4	24.66	15.00	0.5006	0.4999

3.2 Output Data for the 2005 Model

The output data consist of one output file for each category hurricane and input file type except Quantile 2, which was not used in the model, so that in total each category hurricane has six input and five output files. Each output file contains wind velocities, where each row specifies a particular vertex point on the map; the vertex points are distributed in three mile intervals from 0 to 135 E-W and -15 to 45 S-N, where (0,0) represents hurricane landfall in Miami, Florida. Each column of the output file specifies a particular hour of the day, with the final column being the average wind velocity at that particular vertex point. There are 966 vertex points and 100 values per point, such that each column has a total of 966,000 wind velocities. Also of paramount importance is a separate file which labels whether the vertex point is in land or water (For inspection, these files can be seen in appendix 2: Data Files).

Table 3: Sample of 2005 output file used

Input	E-W	S-N	H 0	H 1	H 2	H 3	H 4	H 5	H 6	H 7	H 8	H 9	H 10	H 11	H 12	Max
1	0	-15	51.7	64.1	72.9	67.5	56.8	48	41.1	35.6	31.5	26.8	24.7	23	0	72.9
1	0	-12	44.2	57.6	75.4	69.1	57.9	48.8	41.7	36.1	31.9	27.1	24.9	23.3	0	75.4
1	0	-9	35.4	52.5	77.3	70.5	58.9	49.6	42.3	36.6	32.2	27.4	25.2	23.5	0	77.3
1	0	-6	24.8	49.1	78.8	71.6	59.8	50.3	42.8	37	32.6	27.6	25.4	23.7	0	78.8

3.3 Input Data for the 2010 Model

The 2010 input data for form S-6 is identical to the 2005 data for form S-5, with the exception that the input variables are different. In 2010 the variables used were CP, R_{max} , VT, FFP, and Holland B (a description of the variables can be found in the statistical methodology section). Similarly to the 2005 input files, additional input files were generated for EPR calculations, so that there are a grand total of six input files.

Additionally, a separate file was given which makes it possible to find the exact values for the Holland B parameter given the quantiles in the input file (For inspection, these files can be seen in appendix 2: Data Files).

Table 4: Sample of 2010 input file, all-variable

CP	R _{max}	VT	Holland B Q	FFP
984.5	26.56	18.43	0.6599	1011.27
982.2	25.72	14.19	0.3269	1017.08
987.5	28.76	12.00	0.4751	1018.13
978.4	30.82	17.96	0.0794	1007.43

Table 5: Sample of 2010 additional input file for EPR, only R_{max} variable

CP	R _{max}	VT	Holland B Q	FFP
982.5	26.56	15.00	0.5006	1013.00
982.5	25.72	15.00	0.5006	1013.00
982.5	28.76	15.00	0.5006	1013.00
982.5	30.82	15.00	0.5006	1013.00

3.4 Output Data for the 2010 Model

The output files produced were markedly different from the 2005 results. Instead of having separate files for each hurricane, all hurricane categories were given within a single file; also, the files no longer report wind velocities, but instead report LC directly. These LC values were aggregated throughout time and averaged in two separate ways, creating two output files per input file. The first method averaged LC over all map vertex points, such that 100 LC values were given as output; the second method averaged LC over the 100 values for each vertex point while removing all water points, so that 682 LC values were given as output, one for each point on the map. The reason for this is that the

map was shortened from 2005 to 2010 so that it is now from 0 to 117 E-W and -15 to 45 S-N (For inspection, these files can be seen in appendix 2: Data Files).

Table 6: Sample of 2010 output file by input

Cat	Input	ID	LC
1	1	2345036	3.44
1	2	2772487	4.07
1	3	2228470	3.27

Table 7: Sample of 2010 output file by coordinates

Cat	E-W	S-N	LC
1	6	33	8.3585
1	6	36	6.9207
1	6	39	5.6162

Chapter 4

The R Language, Functions Created, and Results

4.1 Introduction to R

“R is a system for statistical computation and graphics. It consists of a language plus a run-time environment with graphics, a debugger, access to certain system functions, and the ability to run programs stored in script files” (R Project 2012). Due to its nature, R contains a very large library of statistical functions. It also allows the user to create functions to analyze large data sets. The open source nature of R makes it a trustworthy software for calculations, since any sufficiently competent observer can enquire fully about what is actually being computed. “There are no intrinsic limitations to the validation of the software, in the sense that it is all there” (Chambers 2008). Furthermore, “open-source systems demonstrably generate a spirit of community among contributors and active users (...) with a great deal of effort devoted to testing and extension of the systems” (Chambers 2008). Therefore, the large variety of packages readily available for download and the thorough validation of both R and all relevant packages make R a perfect tool to fulfill the S-6 requirements of the FCHLPM for sensitivity and uncertainty analysis.

4.2 R Functions and Results for the 2005 Data

4.2.1 *Loading Function*

In order to perform both SA and UA, several different files had to be loaded into the R interface before any analysis could take place. Therefore, the first piece of code written, the loading loop, is one that allows for both the loading of all necessary files and, at the same time, differentiates between input and output files while numbering them.

The differentiation is possible because all input files are .csv files, while all output files are .dat files. Since the loading loop is searching for all files within a particular folder, it follows the same order as the order of the files in the folder. Therefore the first file in the folder, assuming it is an input file, would be input1 within the R console. The loading and sorting allows for clear distinction between files and they are now ready to be analyzed.

4.2.2 Standardized Regression Coefficients Function and Results

The SRC function as created with the data used for the S-5 form was designed so that a series of matrices could be analyzed, one for each hurricane, and combined into a single matrix of results. For the S-5 form, each matrix was 100 x 5, and the final SRC matrix was 5 x 3. This required the attaching of 100 wind velocity values to the end of the original input file as well as the removal of Quantile 2 (See Figure 1). In order to do this, 966,000 wind velocities had to be sorted and averaged. For each input value, the average over all land based vertex points was found, so that each wind velocity value used is the average over time and over all land based vertex points. Once this column is available, the statistical methodology details how the inverse of the correlation matrix is calculated and then the ratio of the correlations give the SRC values in matrix format. The repetition of this procedure for each hurricane category meant that the matrix produced had 5 rows, one for each variable, and three columns, one for each hurricane category.

An alternate version of the SRC function was also created that is capable of calculating the SRC as described above but at a particular vertex point. Vertex point SRC calculation was required for form S-5 but not S-6, so it was done in order to validate the code. Further discussion of this function can be found within the validation chapter, since

it was one of the results available for the S-5 form. The final results required a graphical representation of the SRC matrix, so a graphing function was created capable of turning the matrix into a line plot, as shown below.

Table 8: SRC matrix based on 2005 data

Category	<i>CP</i>	<i>Rmax</i>	<i>VT</i>	<i>Holland B</i>
1	-0.43	0.23	0.16	0.71
3	-0.26	0.22	0.17	0.82
5	-0.20	0.84	-0.01	0.43

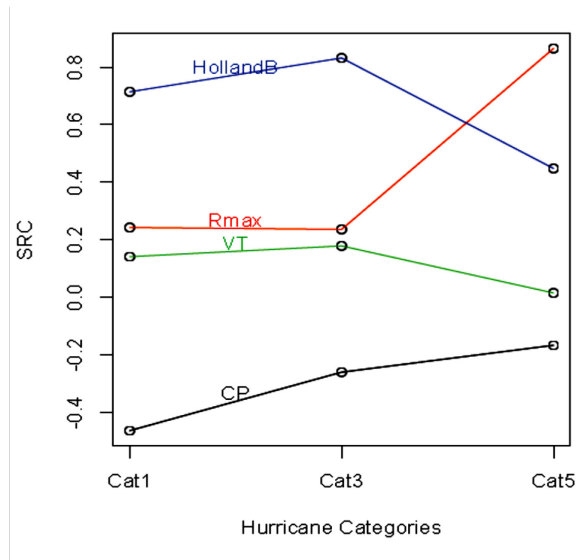


Figure 1: SRC derived from 2005 data

4.2.3 Expected Percentage Reduction Function and Results

The EPR function works with the average over all land based vertex points and over time of the wind velocities. It does this for both all-variable output files as well as output files produced when only a single variable remained unchanged while all other variables were constant. Each of the three hurricane categories used require the same calculations. Once said calculations have taken place, as stated in the statistical

methodology, the variance of each column, where each column represents a different output file, is calculated and then the ratio of each variance in relation to the variance of the all-variable output file is calculated. The output is then stored into a 5 x 3 matrix, one row for each variable, one column for each hurricane category.

Much like the alternate SRC function, an alternate EPR function was also created capable of calculating the EPR at a particular vertex point. Further discussion of this function can be found within the validation chapter, since it was one of the results available for the S-5 form. Furthermore, since the final results for EPR also required a graphical representation of the EPR matrix, the same simple graphing function used for SRC was used for EPR in order to turn the matrix into a line plot, as shown below.

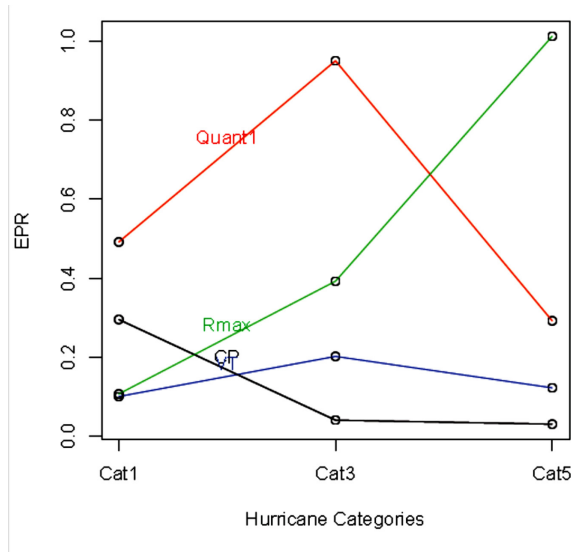


Figure 2: EPR at (30,3) derived from 2005 data

4.2.4 Contour Plot Function and Results

The Contour Plot function, when dealing with wind velocities from the output files, treats these velocities by finding the average over all input values and time, so that there is a single value for each vertex point, where non-land vertex points are replaced

with zeroes. The function then generates a 46 x 21 matrix of the 966 vertex points, with E-W as rows and N-S as columns. The order of all the rows is then inverted from E-W to W-E in order to make sure that the R plotting function, which graphs from left to right, plots the wind velocities correctly. The R plotting function used divides the wind speeds into equal intervals and sorts them by color, with deeper shades of red implying higher velocities, so that a full map of wind velocities for a particular category hurricane in South Florida is created.

Table 9: Sample of sorted matrix based on 2005 data used for Contour Plot

N-S/E-W Coordinates	39	42	45	48
0	64.55	64.471	64.153	64.226
3	65.893	66.889	66.725	66.792
6	67.518	68.309	68.115	68.018
9	69.346	68.848	68.309	68.115

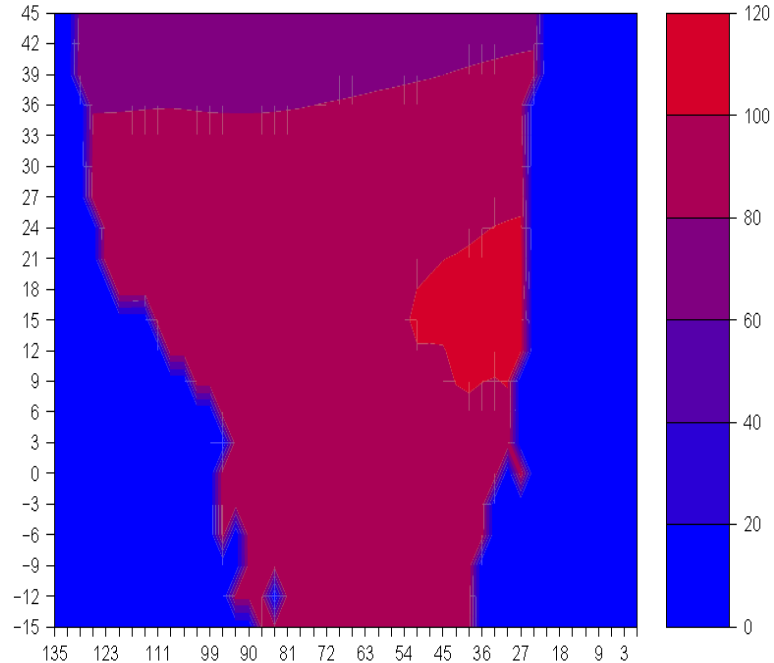


Figure 3: Contour Plot of Maximum Velocity for Category 3 Hurricane

4.3 R Functions and Results for the 2010 Data

4.3.1 *Loading Function*

The loading function used for the 2010 data is almost an exact carbon copy of the 2005 loading function. The only difference is that the output files produced by the 2010 model are not .dat files, but .txt files. Therefore the function now sorts input files versus output files on the basis of whether the file is a .csv file (input) or a .txt file (output).

4.3.2 *Standardized Regression Coefficients Function and Results*

The second version of the SRC function, as created for the S-6 form data, is markedly different from its 2005 counterpart because the output files of the model are so different. The LC values in the output files were already calculated, averaged and returned in sets of 100 for each hurricane category, so that the sorting and averaging of large sets of wind velocities was no longer necessary. Furthermore, since the Holland B values used were made available, it was necessary to replace the Holland B quantile values given in the input file with their actual values, as described in section 3.2. Once these two differences were taken into account, the formation of the 100 x 6 matrix of input files and output results was straightforward. With the 100 x 6 matrix the code that calculates the SRC is the same as the 2005 version, which follows the pre-established methodology. The final result is a 5 x 3 matrix for each variable and hurricane category. The final matrix was graphed using the same function that was used for the 2005 results.

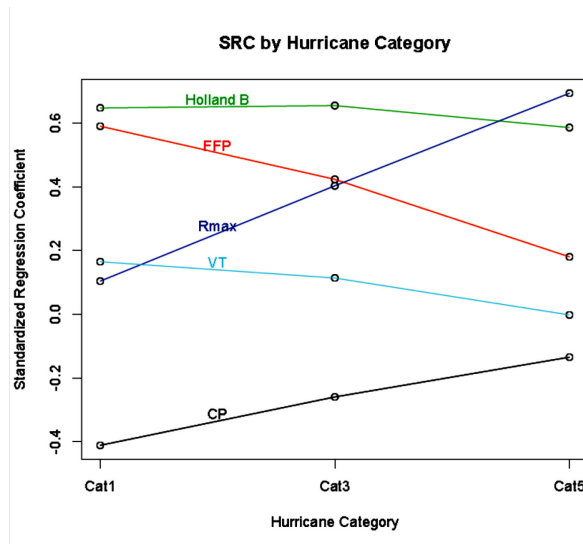


Figure 4: Final Submissions of SRC for form S-6

The final SRC submission shows that, for a category 1 hurricane, changes in the standard deviation of the Holland B parameter and the Far Field Pressure have the largest positive effect on changes on LC deviation. However, as hurricane category increases, Holland B remains significant while FFP decreases significantly. R_{max} and VT are not nearly as influential for a category 1, although R_{max} increases significantly in influence on the standard deviation of LC for category 3 and category 5 hurricanes. Central pressure is of particular interest when looking at category 1 hurricane results due to the strong negative relation between CP and expected loss costs. This relationship decreases as the hurricane increases in intensity.

4.3.3 Expected Percentage Reduction Function and Results

Similar to the SRC version for form S-6, the main distinction between the EPR function for form S-6 and the 2005 version is the format of the output files. Since the LC results were given directly in the output files and they were already averaged, the creation of a matrix of LC results for the different output files is almost immediate, at which point

the EPR calculations are done using the same process as the 2005 version, based on the pre-established methodology. This creates a 5 x 3 matrix for each variable and hurricane category. The final matrix was graphed using the same function that was used for the 2005 results.

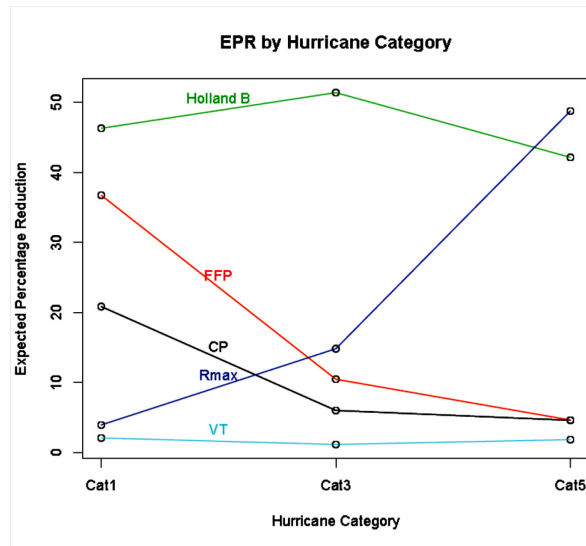


Figure 5: Final Submissions of EPR for form S-6

The final submission for EPR shows that the Holland B parameter and the FFP are largely responsible for the variance of LC for a category 1 hurricane, with CP being less significant, and R_{max} and VT being insignificant. Category 3 hurricanes continue to have the Holland B parameter as predominantly significant, with R_{max} gaining significance while all other variables lose it. Category 5 hurricane variance of LC is predominantly explained by R_{max} and the Holland B parameter, while all other variables are insignificant.

4.3.4 Contour Plot Function and Results

The Contour Plot function that analyzed the data given to perform S-6 is different from the 2005 version since the output file used for the contour plots already has the LC

calculated and averaged over the 100 input values. The 2010 data contains LC for each vertex point excluding all water based points. In order to properly plot the LC it is therefore necessary to reintroduce the water based points so a complete matrix for E-W and N-S vertex points can be generated. Once this is achieved the plotting mechanism is the same as the one used to plot the 2005 contour plots.

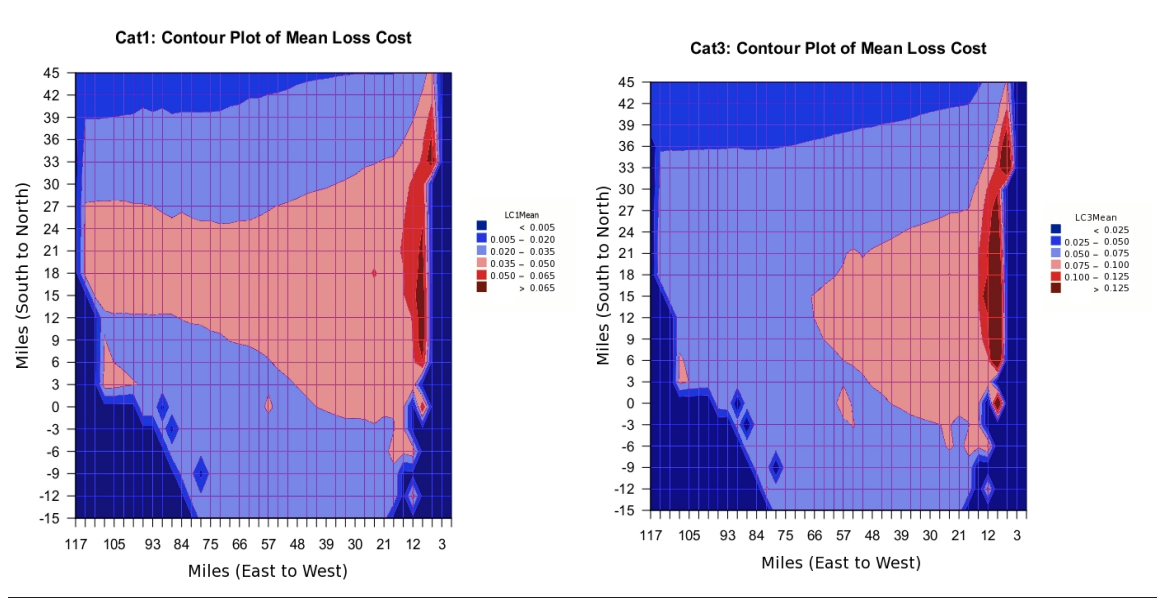


Figure 6: Cat 1 Contour Plot of Mean Loss

Cost based on 2010 data

Figure 7: Cat 3 Contour Plot of Mean Loss

Cost based on 2010 data

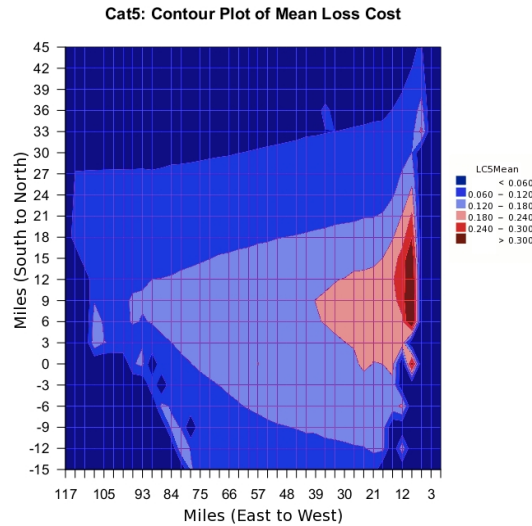


Figure 8: Cat 5 Contour Plot of Mean Loss Cost based on 2010 data

The contour plots show the mean LC across South Florida presented as a proportion of the total exposure. The category 1 hurricane contour plot shows maximum mean LC of .065, is contained primarily in the immediate landfall area. The category 3 contour plot shows mean LC greater than .05 throughout most of the map, with a maximum mean LC of .120 in the immediate landfall area. The category 5 contour plot shows a mean LC greater than .12 stretching from east to west through the center of South Florida, with a maximum mean LC of .300 in the immediate landfall area. The stark differences in the plots show how an increase in hurricane intensity implies a significant increase in mean expected loss costs.

4.3.5 Cumulative Relative Frequency Function and Results

The Cumulative Relative Frequency function used is a preexisting R function that was formatted to fit the necessary plotting needs of form S-6. No earlier version was created when working with the data from form S-5 due to the straightforward nature of

the task. Validation was done through functional testing. Predetermined data sets of data were created to compare function results with expected results; all testing proved successful.

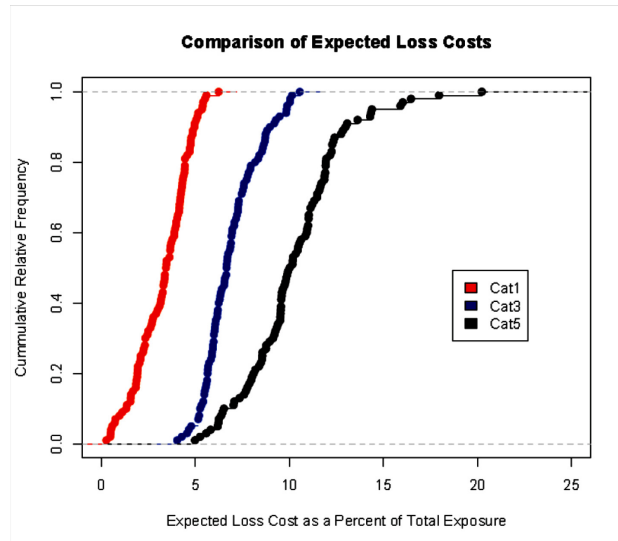


Figure 9: CRF based on 2010 data

The cumulative relative frequency graph produced for the final submission shows that, as a percentage of total exposure, expected loss costs for a category 5 are significantly larger than those of a category 1 or a category 3 hurricane.

Chapter 5

Validation

5.1 Validation Methodology

Whenever computer programming methods are used to calculate results, the importance of validating the code cannot be understated. Without proper validation it is impossible to be certain of the results generated by any of the functions written. Each piece of the code must therefore be validated separately, and even functions that are part of R libraries were checked to make sure all results were valid despite previous validation by the R community.

The two methods used to validate the R functions created were either through direct comparison to results from form S-5, or through traditional validation methods such as formal testing, functional testing or random testing (Tran 1999). The main method used when results from form S-5 were not available due to the differences between requirements for forms S-5 and S-6 was a walk-through. Walk-throughs consist of running through a function one line of code at a time, in order to see if the expected results are generated in a piece-meal fashion. The second method used, aside from the walk-through, was the testing of functions with test-case files in order to see if pre-determined results were generated.

5.2 Validation of the 2005 Functions

5.2.1 Loading Function Validation

The loading loop was validated through a simple process. Any of the files that were loaded into R were also opened through Windows Excel. Making sure that the files were properly loaded was merely a matter of matching the files in R with the Windows Excel files. Since the function being used to read each of the files was part of the main R library, its validation was not required. It was, however, necessary to check that all input and output files had been loaded and correctly differentiated in order to make sure that, when other functions called on them, the correct files would be brought forth.

5.2.2 Standardized Regression Coefficients and Expected Percentage Reduction Validation

Validating the SRC and the EPR code for form S-5 was done in several stages. First, it was necessary to make sure that the sorting and averaging of all vertex points so that a set of 100 average wind velocities could be used was done correctly. Because R is a functional language, this was validated by running the code one line at a time and then randomly comparing some of the sorted sets of values with the original unsorted ones. Once walk-through validation was done, and knowing that functions like mean or variance are inherent to R, final validation of the SRC and the EPR code was done by comparing the wind velocity results produced by the functions with the original 2005 S-5 SRC and EPR results based on expected loss costs. Because of the close relationship between wind velocity and LC, it was expected that the two graphs would be extremely similar.

The SRC and the EPR were further validated through the creation of variations on the code to allow for the analysis of wind velocities both at particular vertex points and throughout time intervals. Both of these were also compared to S-5 SRC and EPR results based on the 2005 expected loss costs. Further validation was done through the creation of test-case files where all variables were made constant to see if the SRC and EPR calculated returned the expected results.

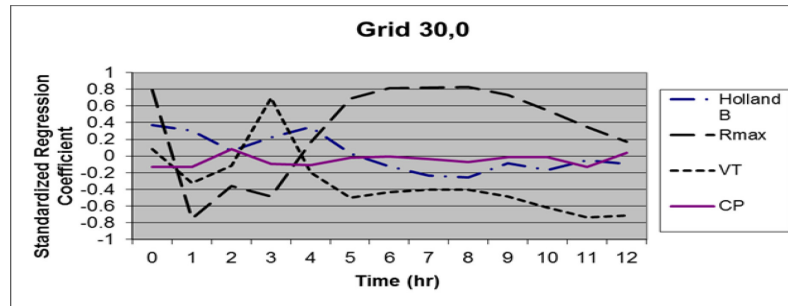


Figure 10: SRC for LC at (30,0) as submitted for form S-5 in 2005

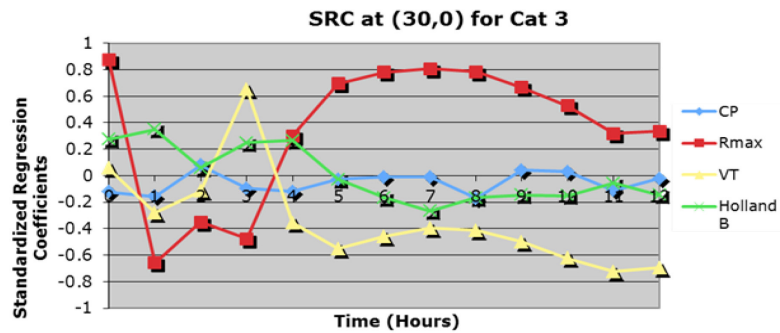


Figure 11: SRC for V_{max} at (30,0) as generated for validation based on the data for form S-5 in 2005

5.2.3 Contour Plot Validation

Validating the S-5 Contour Plot function was extremely similar to the validation of the SRC and EPR functions since validation of averages calculated had to take place. For the Contour Plot function, averages were calculated over all input values to return a mean V_{max} for each vertex point. Randomized testing of the averages generated for some

of the 966 vertices showed consistency. After this, the replacement of average V_{\max} values with zeroes where water was present according to the Land-Water ID file was done and then the contour plot function used to graph was a part of a pre-existing R package. The ultimate validation of the S-5 Contour Plot function is the Contour Plot itself, which is a clear representation of south Florida and can be easily read and compared to the 966 average vertex values.

5.3 Validation of the 2010 Functions

5.3.1 *Loading Function Validation*

Since the only change required in the loading function was a single line of code that specified that output files from the model were .dat, which was changed to .txt for the 2010 results, no validation other than the comparison between loaded files and the actual files was deemed necessary.

5.3.2 *Standardized Regression Coefficients and Expected Percentage Reduction Validation*

The 2010 versions of the SRC and EPR functions required the removal of the initial part of the code that sorted and averaged out the data, since this was already done to the output files. Other than that the functions remained unchanged, and therefore previous validation was deemed appropriate. However, due to the importance of having results that were correct, a walk-through of the code was once again done to corroborate the results.

5.3.3 *Contour Plot Validation*

The validation of the S-6 Contour Plot function was done particularly carefully, since results generated by the original S-6 output files did not reflect what was expected by the modeling team; it was later discovered that there were inaccuracies in the output files generated by the model and new files were generated. The major changes in the output files made the validation very straightforward since the output file used for form S-6 was already averaged for each vertex, making it unnecessary for the function to do so. The removal of water vertices in their entirety in the output file made it necessary to reintroduce zeroes representing water vertices in order to properly plot the south Florida area. Validation of the S-6 Contour Plot was done by comparing it to the S-5 Contour Plot to show that both plots depict a map of South Florida when using a test file with 0 for water values and 1 for land values. The only distinction is the removal of a large portion of the water vertex values that are east of Florida for form S-6 when compared to form S-5.

Chapter 6

Final Results and Recommendations

6.1 Final Results

The focus of the previously described analysis was the necessity of analyzing the linear model in order to meet the criteria of the Florida Commission on Hurricane Loss Projection Methodology. The importance of sensitivity analysis and uncertainty analysis for a public model whose main purpose is to give appropriate estimates for expected loss costs due to hurricane damages cannot be understated. Sensitivity, as seen in the standardized regression coefficient results, establishes how changes in model input produce changes in model output while uncertainty, as seen in the expected percentage reduction results, studies how much variation in model output is caused by model inputs. The final results presented to the Florida Commission on Hurricane Loss Projection Methodology for sensitivity analysis show that the Holland B parameter is of constant significance, while R_{\max} increases in significance as the hurricane category increases. This is not only relevant but also consistent with previous models. Furthermore, the relation with the uncertainty, as seen in the expected percentage reduction results, cannot be denied, since the same pattern is exhibited by the Holland B parameter and R_{\max} once more.

The final contour plots produced for the Florida Commission on Hurricane Loss Projection Methodology show an increase in expected loss costs as the hurricane category increases. Within each separate plot a decrease in expected loss costs from east to west can be observed, as is expected due to the weakening of a hurricane on land. Before the final submission for the S-6 form was made, several different contour plots were

generated using different output results from the model based on changes in the input files. All versions can be found in the USB file containing all documentation.

The creation of a series of R functions capable of doing the analysis was useful not only in the short term for form S-6, but for any future sensitivity analysis and uncertainty analysis that needs to be done. The code has been thoroughly validated and is properly commented, which makes it possible for anyone with a working knowledge of R to quickly generate future results provided no major changes occur to the format of the input and output files. Even if such changes were to take place, the core standardized regression coefficients and expected percentage reduction calculations need not be changed, only the sorting of the data into the appropriate format.

Having had the 2005 data for form S-5 as well as the final results in order to both generate the original code and validate it made it possible to create all of the necessary functions months ahead of schedule. Once the first set of output files for form S-6 were released, the necessary changes to the functions were done with plenty of time, so that when the output files generated for form S-6 changed due to changes in the model, regenerating form S-6 results was nearly immediate. This highlights the importance of computer programming for data analysis.

Since the model presented by FIU was approved after very extensive and rigorous review by a panel of experts, the analysis performed can be deemed a success. Future success will be measured based on the usability of the code for future hurricane model submissions.

6.2 Recommendations

The changes from the 2005 to the 2010 output file format made it necessary to both edit the code and revalidate it for any possible inaccuracies. It also made part of the work done when creating the 2005 functions unnecessary and/or invalid. In order to make sure that future submissions to the Florida Commission on Hurricane Loss Projection Methodology of sensitivity analysis and uncertainty analysis are done smoothly using the functions created for form S-6, it is of particular importance that the modeling team maintains consistency in the format of the output files.

The requirements of the Florida Commission on Hurricane Loss Projection Methodology for sensitivity analysis carry the underlying assumption that the hurricane model is linear in nature, since standardized regression coefficients are used. The “SRC gives information on the linear regression model” (Saltelli et al. 1999) but if the model is nonlinear and not monotonic it is necessary to have “SA that is independent from assumptions about the model structure” (Saltelli et al. 1999). Nonlinear model sensitivity analysis methods include the extended FAST and the Sobol. The extended FAST method “is generally more efficient than the method of Sobol” since “the total indices are computationally more expensive than both the correlation/regression measures and screening tests such as that of Morris” (Saltelli et al. 1999). And although “Sobol’s method (...) has the capability to calculate higher-order effects, whereas extended FAST is limited to total effects” (Shott) of all factors, the extended FAST method is sufficient for the analysis required by the commission. The extended FAST method computes “the total (all-effects) contribution of each factor to the output variance” (Saltelli et al. 1999) in the manner described by Saltelli in *Global Sensitivity Analysis of Model Output*.

It is therefore recommended in the future that sensitivity analysis using the extended FAST method should be conducted. This analysis cannot be done using the current model data, due to the computational cost of the analysis. The current model only has 100 observations available, and for a model with 5 factors the minimum necessary number of model evaluations is 325. This is given by the formula given by Saltelli et al. (1999):

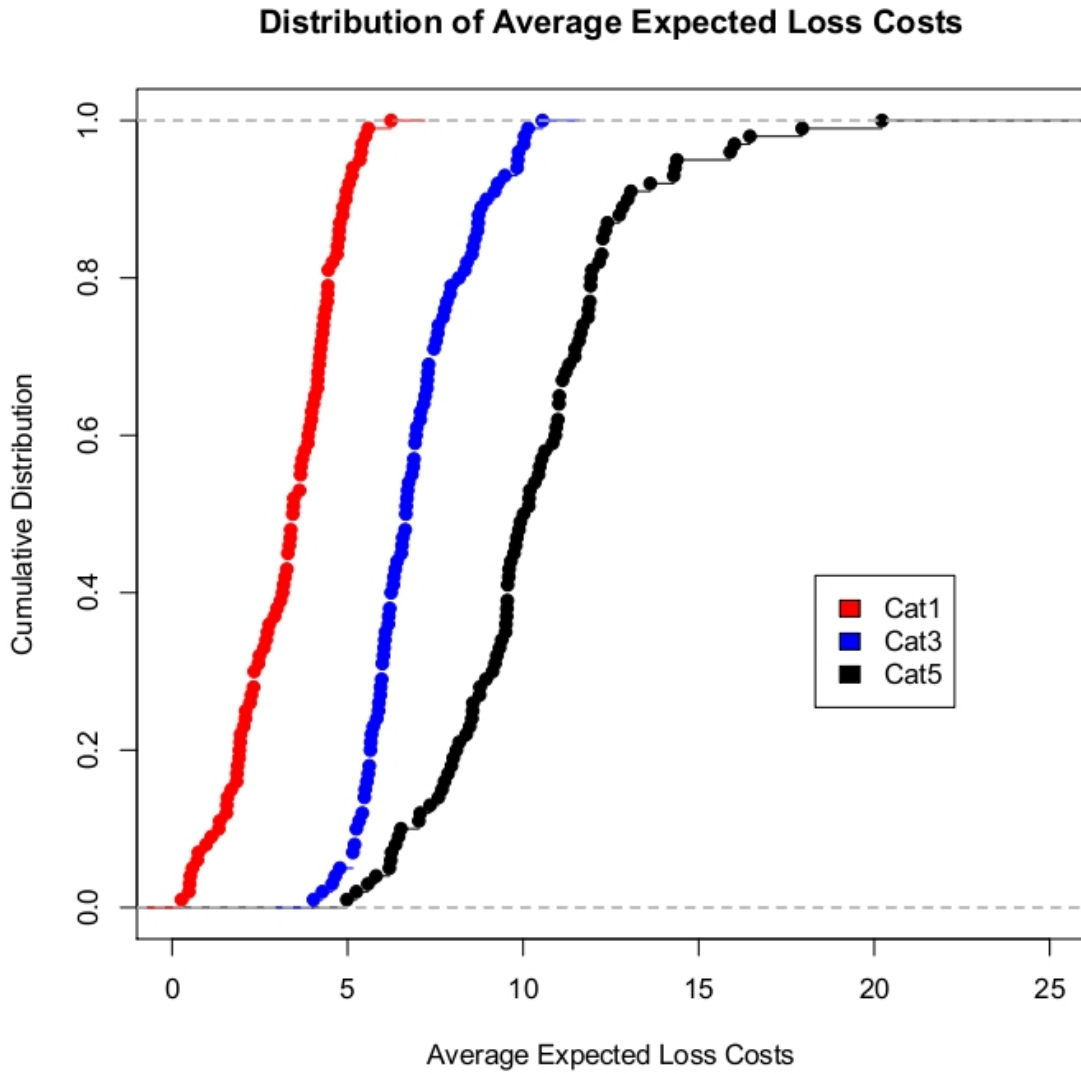
$$C = nN_rN_s \text{ where } N_s = (2M\omega_{max} + 1)$$

For this cost formula n is the number of factors, N_r is the number of curves used (minimum value of 1), and N_s is defined by M , the interference factor, and ω_{max} , the largest among the set of frequencies. The sensitivity package created for R (Pujol), which is capable of calculating the extended FAST analysis for a given model has a minimum value for N_s of 65, which is considered by Saltelli et al (1999) to be a value outside the recommended region due to its small magnitude.

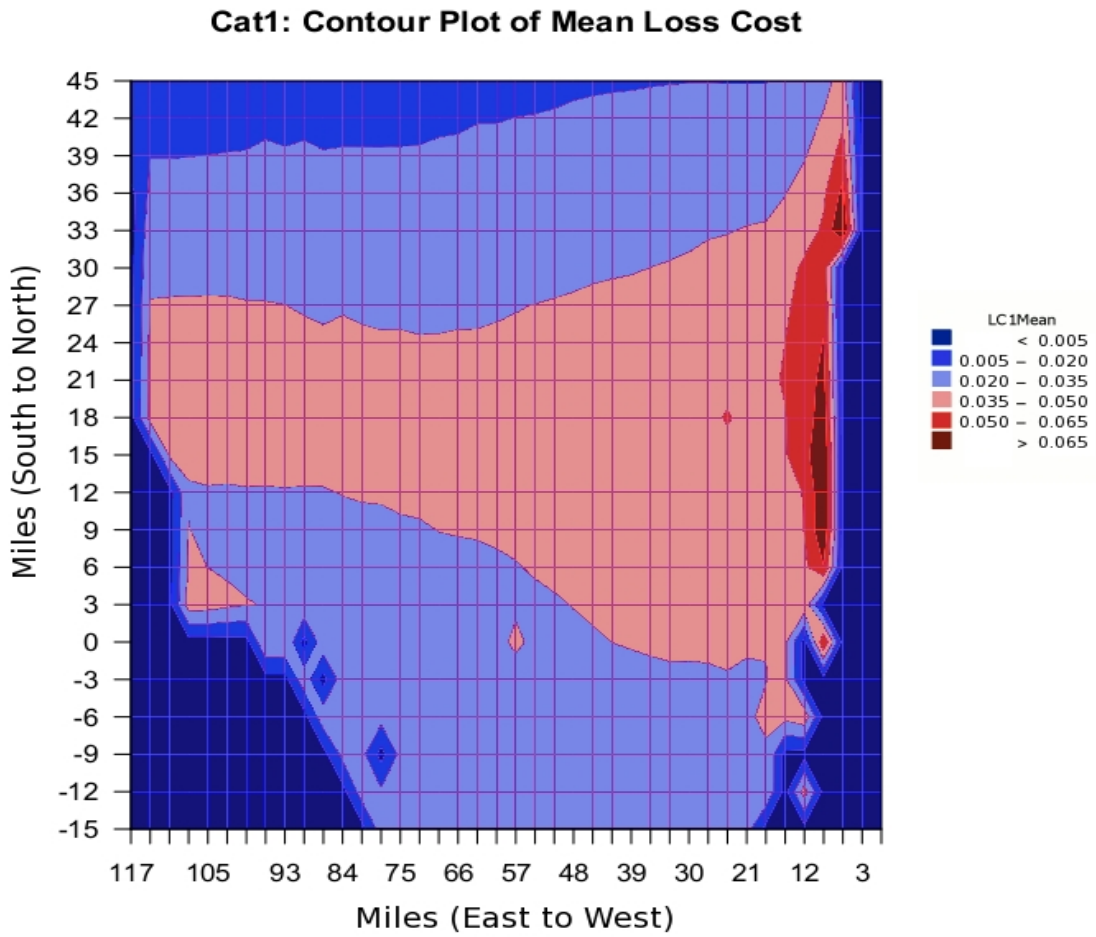
APPENDICES

Appendix I: Results for form S-6 presented to FCHLPM

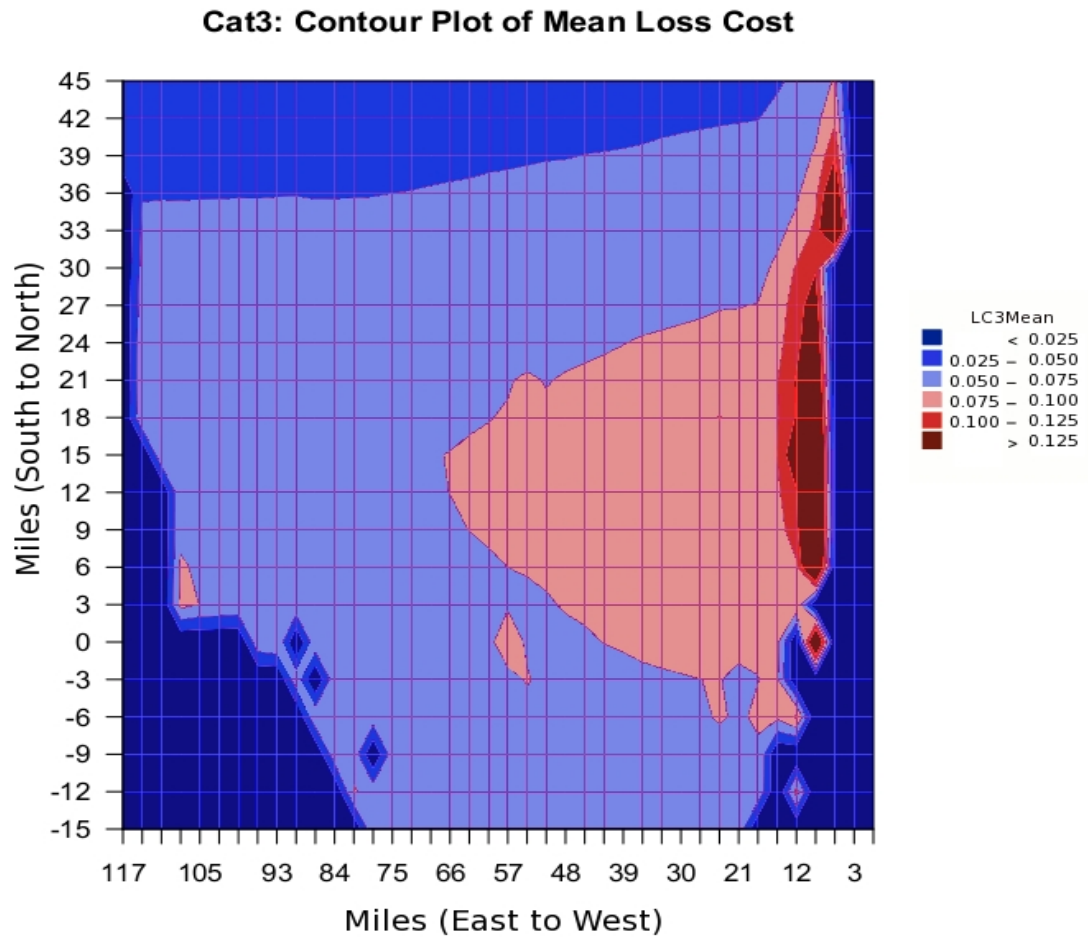
A. Cumulative Relative Frequency Distribution



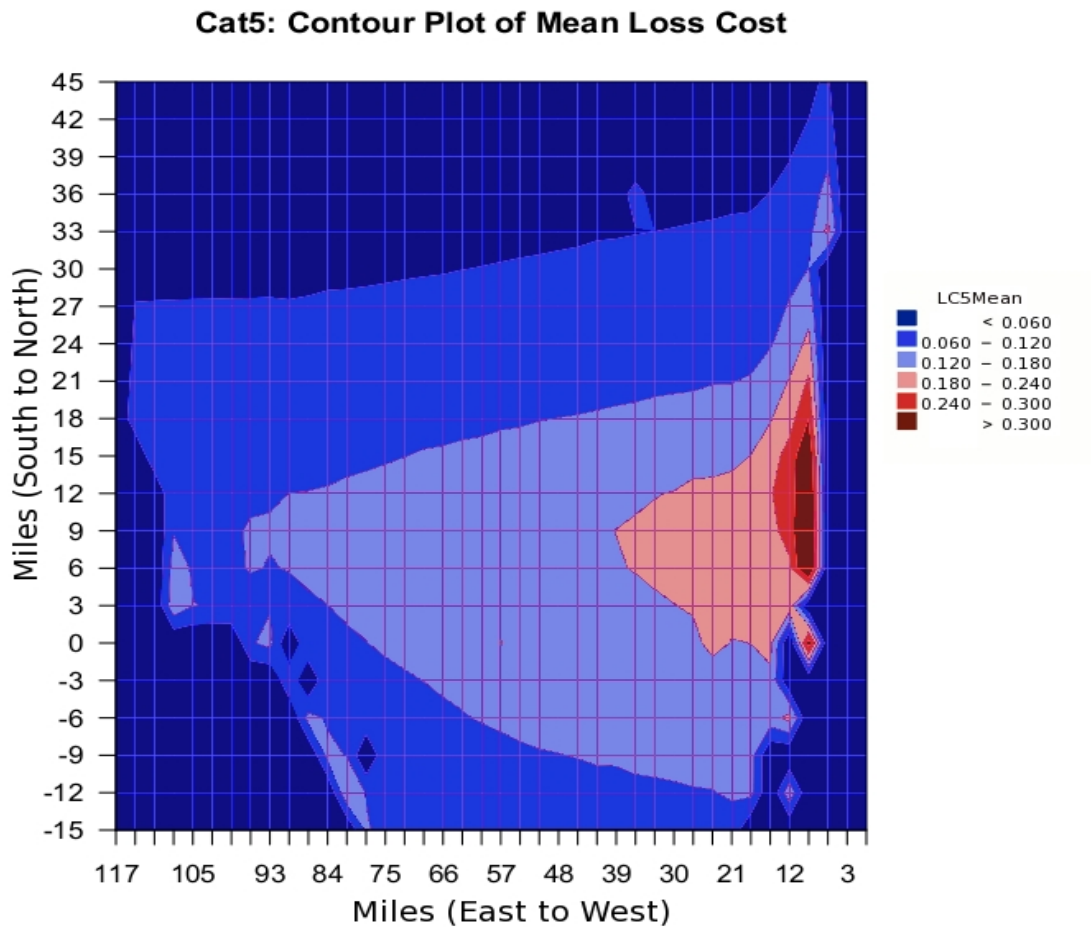
B. Contour Plot for Category 1 Hurricane



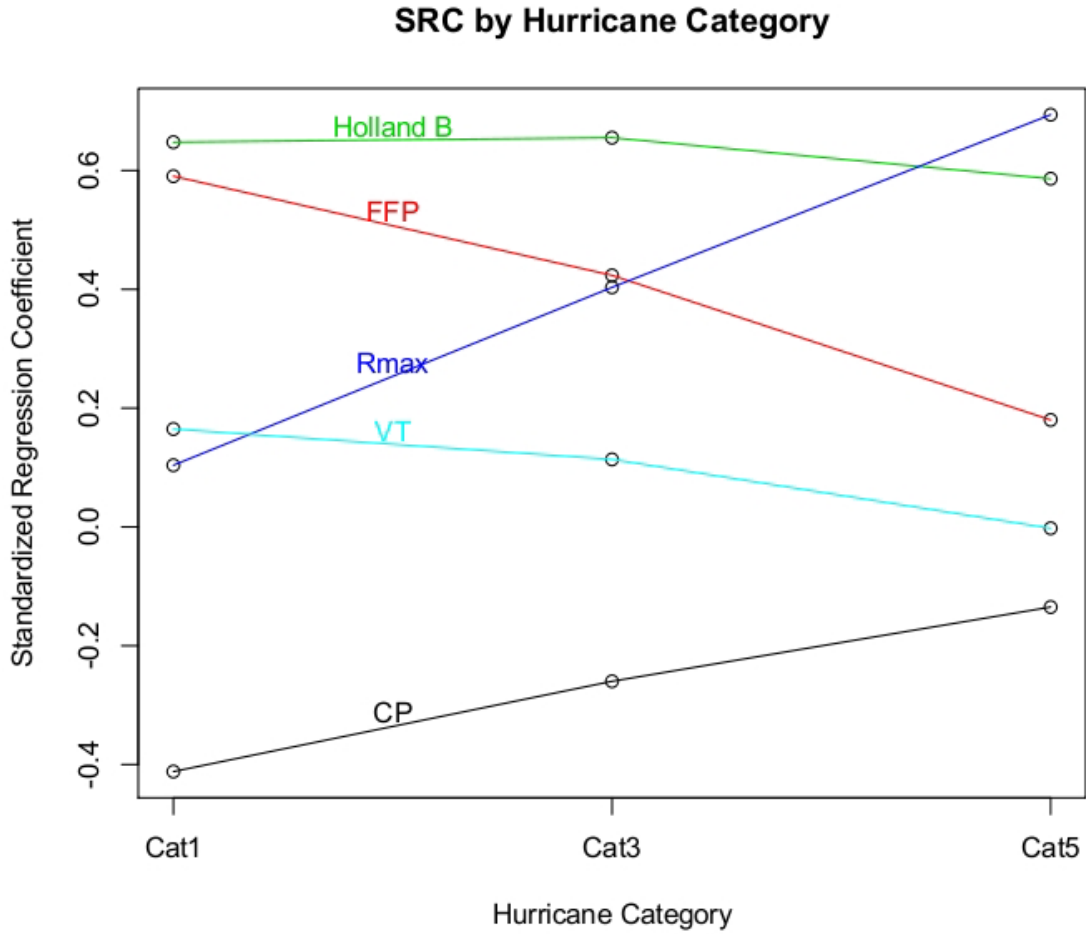
C. Contour Plot for Category 3 Hurricane



D. Contour Plot for Category 5 Hurricane

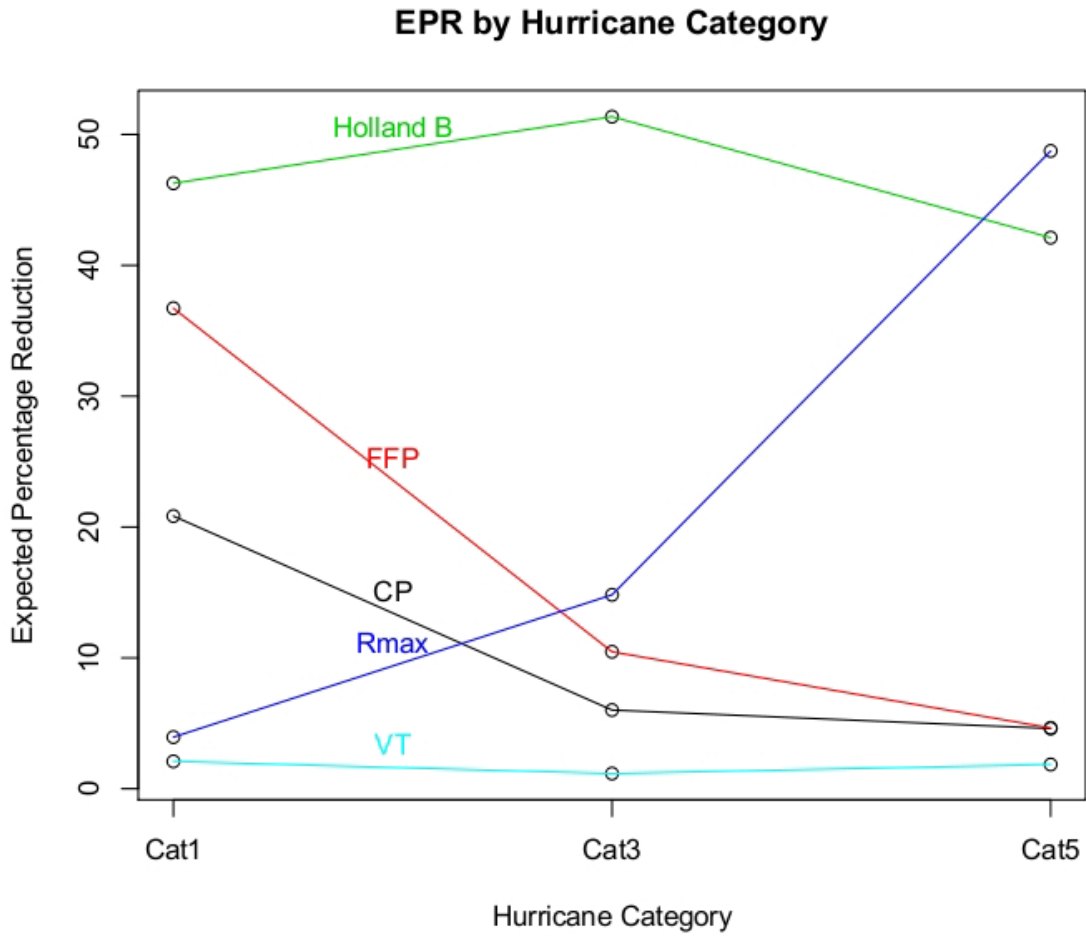


E. Standardized Regression Coefficients by Hurricane Category



Category	<i>CP</i>	<i>Rmax</i>	<i>VT</i>	<i>Holland B</i>	<i>FFP</i>
1	-0.4118	0.1039	0.1648	0.6477	0.5905
3	-0.2599	0.4033	0.1137	0.6552	0.4236
5	-0.1349	0.6939	-0.0022	0.5862	0.1801

F. Expected Percentage Reduction by Hurricane Category



Category	<i>CP</i>	<i>Rmax</i>	<i>VT</i>	<i>Holland B</i>	<i>FFP</i>
1	20.8398%	3.9463%	2.0921%	46.2717%	36.7245%
3	6.0155%	14.8201%	1.1625%	51.3594%	10.4668%
5	4.6087%	48.7428%	1.8529%	42.1176%	4.6455%

Appendix II: Programming Code for Functions Used

A. Loading Function

Loading Loop loads all appropriate files from working directory and saves into list_of_files the names of all the output files in order, which is used for Uncertainty Calculations.

```
> filenames = list.files(".")
> list_of_files=character()
> for( i in 1:length(filenames))
{
  ## break files into two words on the period in order to make a distinction between
input and output files
  filename <- unlist(strsplit(filenames[i], "\\."))
  if( filename[2] == "csv")
  {
    fd<-read.csv(file= filenames[i], header=TRUE, sep=",")
    name<-paste("input",i,sep=".")
    assign(name,fd)
  }
  else if( filename[2] == "txt")
  {
    fd<-read.csv(file=filenames[i], header=FALSE, sep="")
    name<-paste("output",i,sep=".")
    assign(name,fd)
    list_of_files<-append(list_of_files,name)
  }
}
```

B. SRC Function

```
## All code is dependent on the format of the input and output files.
SRCMatrixFunc<-function(SA1,SA1Column,inputcat1,inputcat3,inputcat5,HollandB)
{
  ## initializes and then creates the three vectors of 100 values for the SA
  outputcat1<-numeric(0)
  outputcat3<-numeric(0)
  outputcat5<-numeric(0)

  ## Sorts HollandB values to be used throughout the system
  HolB<-as.matrix(HollandB)
  HolB<-HolB[,16]
  HolB<-sort(HolB,decreasing=FALSE)
```



```

HolB<-as.numeric(HolB)

for(i in 1:nrow(SA1))
{
  if(i < 101)
  {
    outputcat1<-append(outputcat1,SA1[i,SA1Column])
  }
  else if(i<201)
  {
    outputcat3<-append(outputcat3,SA1[i,SA1Column])
  }
  else if(i < 301)
  {
    outputcat5<-append(outputcat5,SA1[i,SA1Column])
  }
}

## Creates list of output files, later will use get function to find them to calculate the
SRC
output_files<-c("outputcat1","outputcat3","outputcat5")

## Creates list of input files, the get function will be used to find them to calculate the
SRC
input_files<-c("inputcat1","inputcat3","inputcat5")

## Initialize output matrix, the number of rows is 2 less than the number of columns in
the input file since both the Quantile parameter and the CF are removed.
SRCMatrix<-matrix(nrow=ncol(inputcat1)-2)

## Names of rows of final output matrix, SRCMatrix, then removes the name of the
5th column, which is the CF and the 7th, which is the Quantile. It calls it the 6th due to
the fact that the removal of the 5th makes the 7th the 6th.
Rows<-colnames(inputcat1)
Rows<-Rows[-5]
Rows<-Rows[-6]

## Names of Columns of final output matrix, SRCMatrix
Columns<-c("Cat1", "Cat3", "Cat5")

## loop calculates the SRC for each input/output file combination (there are 3, one for
each category hurricane) and appends it to the SRC Matrix
for (i in 1:length(output_files))
{

```

maxfinal is a matrix of the original input data, which is called based on the get function in order to append the 100 value vector to it and then calculate the correlation matrix. MeansVector is the vector of 100 values for the output data based on the loop that created the three vectors earlier.

```
maxfinal<-as.matrix(get(input_files[[i]])
MeansVector<-get(output_files[[i]])

HolBF<-numeric(0)
for(i in 1:nrow(maxfinal))
{
  HolBF<-append(HolBF,quantile(HolB,probs=maxfinal[i,4]))
}
HolBF<-as.numeric(HolBF)
```

SensMatrix is the combination of the 100 input values for each one of the variables along with a final column, the MeansVector. Notice that SensMatrix removes the 4th column of maxfinal, which would be the Holland B quantile, and replaces it with the Holland B values.

```
SensMatrix<-
matrix(cbind(maxfinal[,1:3],HolBF,maxfinal[,6],MeansVector),nrow=100)
```

Calculates the inverse of the correlation matrix of the SensMatrix, which will be used to calculate the SRC

```
Cor1<-solve(cor(SensMatrix))
SRC<-numeric(0)
```

q is used to simplify the next loop, which will be the calculation of each SRC. Remember the SRC is the ratio of the last row of the inverse of the correlation matrix to the last element of the inverse of the correlation matrix.

```
q<-ncol(SensMatrix)
for(l in 1:(q-1))
{
  SRC<-append(SRC,((-Cor1[l,q])/(Cor1[q,q])))
}
SRCMatrix<-cbind(SRCMatrix,SRC)
}
```

```
## Removes the initial NA column within SRCMatrix
SRCMatrix<-SRCMatrix[,2:ncol(SRCMatrix)]
```

Names both the rows and the columns of the SRCMatrix, then returns the SRCMatrix

```
SRCMatrix<-
matrix(SRCMatrix,ncol=ncol(SRCMatrix),dimnames=list(Rows,Columns))
```

```

SRCMatrix
}

```

C. EPR Function

```

## Function depends on the format of the output files and their sorted order.
UncMatrixFunction<- function(VColumn,NumberOfFilesPerCat)
{
## Initialize vector of variances which will be calculated
VarsVector<-numeric(0)
MeansVector<-matrix(nrow=100)
## Loop gets all the .txt files, which are the output files, and for each one it grabs the
specified column (VColumn), sorts it appropriately so that MeansVector has Cat1, Cat3,
Cat5 for file one, again for file two, etc... and removes the last two files, which are the
Holland B track file and the contour plot file.

for (i in 1:(length(list_of_files)-2))
{
Vmax<-get(list_of_files[[i]])
outputcat1<-numeric(0)
outputcat3<-numeric(0)
outputcat5<-numeric(0)

for(i in 1:nrow(Vmax))
{
if(i < 101)
{
outputcat1<-append(outputcat1,Vmax[i,VColumn])
}
else if(i<201)
{
outputcat3<-append(outputcat3,Vmax[i,VColumn])
}
else if(i < 301)
{
outputcat5<-append(outputcat5,Vmax[i,VColumn])
}
}
}
MeansVector<-cbind(MeansVector,outputcat1,outputcat3,outputcat5)
}
## Removes 1st column of null values, so that we have 18 columns, 3 for each variable
CP, FFP, Quantile, Rmax, SA, and VT.
MeansVector<-MeansVector[,2:ncol(MeansVector)]

```

```

## Calculates the variance for each of the columns and appends it to the variance vector
for(j in 1:ncol(MeansVector))
{
  VarsVector<-append(VarsVector,var(MeansVector[,j]))
}
## VarsMatrix is a matrix which breaks the VarsVector into 3 columns, where each
column is the data for one of the hurricanes, First row is CP, second is FFP, 3rd is
Quantile, 4th is Rmax, 5th is SA, and 6th is VT.
VarsMatrix<-t(matrix(VarsVector, ncol=6))
UncMatrix<- numeric(0)

## Names of rows of UncMatrix
Rows<-c("CP","FFP","Holland B","Rmax","VT")

## Names of Columns of UncMatrix
Columns<-c("Cat1", "Cat3", "Cat5")

## loop calculates the ratio of variances for each of the category hurricanes based on the
number of files per category hurricane (including the original output file). The files are
ordered such that VarsMatrix[5,] is the original output file.
for (i in 1:length(VarsMatrix))
{
  if (i <= NumberOfFilesPerCat)
  {
    p<- 1
    UncMatrix[[i]]<-(VarsMatrix[[i]]/(VarsMatrix[5,p]))
  }
  else if (i <=(2*NumberOfFilesPerCat))
  {
    p<- 2
    UncMatrix[[i]]<-(VarsMatrix[[i]]/(VarsMatrix[5,p]))
  }
  else if (i <=(3*NumberOfFilesPerCat))
  {
    p<- 3
    UncMatrix[[i]]<-(VarsMatrix[[i]]/(VarsMatrix[5,p]))
  }
}

## convert UncMatrix into a matrix with 3 columns, then removes the 5th row, which
would be a row of 1s, and then names the rows and columns of the matrix appropriately.
UncMatrix<-matrix(UncMatrix,ncol=3)
UncMatrix<-UncMatrix[-5,]
UncMatrix<-UncMatrix*100
UncMatrix<-matrix(UncMatrix,ncol=ncol(UncMatrix),dimnames=list(Rows,Columns))

```

```

UncMatrix
}

```

D. SRC and EPR Plotting Function

```

## Simple function can plot both the Sensitivity and Uncertainty matrices.
SUPlotFunction<-function(SUMatrix,Plot.Title,Y.Title)
{
  x.coord<-c(1,2,3)
  Plot.Title<-as.character(Plot.Title)
  Y.Title<-as.character(Y.Title)
  plot(col(SUMatrix),SUMatrix,xaxt="n", main=Plot.Title, xlab="Hurricane Category",
ylab=Y.Title)
  axis(side=1,at=x.coord,labels=colnames(SUMatrix))
  for(i in 1:nrow(SUMatrix))
  {
    lines(SUMatrix[i,], col=i)

text(1.5,mean(SUMatrix[i,1:2])+max(SUMatrix)/30,labels=rownames(SUMatrix)[i],col=
i)
  }
}

```

E. Contour Plot Function

Function returns Mean Loss Cost. Must include library(gplots) at the beginning.

```

> ContourPlot<-
function(CatOutput,HurricaneCat,EWEndCoordinate,NSEndCoordinate,
Colors,LandWater,NSVertexPoints,Plot.Title)
{
  ## Creates matrix of wind values and creates names for the rows and columns of the
  final matrix based on sequences. EWEndCoordinate and NSEndCoordinate make it
  possible to adjust the map, since the 2006 and 2010 maps may have different total
  North-South points (0,135) vs (0,120).

  LandMatrix<-numeric(0)
  if(HurricaneCat == 1)
  {
    j=1
    for(i in 1:nrow(LandWater))
    {
      if(LandWater$ID[i] == 0)
      {
        LandMatrix<-append(LandMatrix,LandWater$ID[i])
      }
    }
  }
}

```

```

    }
    else if (input.31$ID[i] == 1)
    {
      LandMatrix<-append(LandMatrix,CatOutput$V4[j])
      j=j+1
    }
  }
}
else if(HurricaneCat == 3)
{
j=683
for(i in 1:nrow(LandWater))
{
  if(LandWater$ID[i] == 0)
  {
    LandMatrix<-append(LandMatrix,LandWater$ID[i])
  }
  else if (input.31$ID[i] == 1)
  {
    LandMatrix<-append(LandMatrix,CatOutput$V4[j])
    j=j+1
  }
}
}
else if(HurricaneCat == 5)
{
j=(682*2)+1
for(i in 1:nrow(LandWater))
{
  if(LandWater$ID[i] == 0)
  {
    LandMatrix<-append(LandMatrix,LandWater$ID[i])
  }
  else if (input.31$ID[i] == 1)
  {
    LandMatrix<-append(LandMatrix,CatOutput$V4[j])
    j=j+1
  }
}
}
}

Columns<-seq(0,EWEndCoordinate,3)
Rows<-seq(-15,NSEndCoordinate,3)

```

```
## Makes LandMatrix into matrix with row and column names based on earlier
established sequences.
```

```
ContourMatrix<-matrix(LandMatrix,nrow=NSVertexPoints,
dimnames=list(Rows,Columns))
```

```
## Rewrites Column Order Backwards to set up for graphing.
```

```
ContourMatrix <- ContourMatrix[,ncol(ContourMatrix):1]
```

```
## Takes transpose of matrix to prepare it as x-y coordinates for graphing
ContourMatrix<-t(ContourMatrix)
```

```
## Function within a function, sets up the axes for the graph.
```

```
ContourPlotAxes<- function(ContourMatrix)
{
## Does the y coordinates, from -15 to 45 (columns)
y.coord <- (1:dim(ContourMatrix)[2] - 1) / (dim(ContourMatrix)[2] - 1);
y.axis<-axis(side=2, at=y.coord, labels=colnames(ContourMatrix), las=1);
## Does the x coordinates, from 0 to 135 (rows)
x.coord <- (1:dim(ContourMatrix)[1] - 1) / (dim(ContourMatrix)[1] - 1);
x.axis<-axis(side=1, at=x.coord, labels=rownames(ContourMatrix), las=1);
}
```

```
## Creates the plot to be seen, with variable colorpanel number and title. Levels were
edited within the code for each category hurricane due to last minute changes required
in the plotting.
```

```
Plot.Title<-as.character(Plot.Title)
ContourCat<-filled.contour(ContourMatrix, col=colorpanel(Colors, "blue","red"),
levels=c(.00,.005,.010,.015,.020,.025,.1), plot.axes=ContourPlotAxes(ContourMatrix),
main=Plot.Title)
ContourCat
}
```

F. CRF Function

```
plot(ecdf(output.29[201:300,4]),xlim=c(0,25),main="Distribution of Average Expected
Loss Costs",xlab="Average Expected Loss Costs",ylab="Cummulative Distribution")
lines(ecdf(output.29[101:200,4]),col='blue')
lines(ecdf(output.29[1:100,4]),col='red')
legend(locator(n=1),c("Cat1","Cat3","Cat5"),fill=c("red","blue","black"))
```

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